Microvascular anatomy of the anterior surface of the medulla oblongata and olive

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The arterial supply and the microanatomy of the anterior surface of the medulla oblongata and olive were studied in 11 cadaveric specimens, with investigation of the size, course, and length of the arteries. Two distinct anatomical entities divide the vascular supply in this region: 1) the pyramid, which is the anterior surface of the medulla; and 2) the olive, which is adjacent to the lateral aspect of the pyramid. Primary vascularization of the pyramid was via small branches of the anterior spinal artery, a branch of the vertebral artery. Minute perforators from the anterior spinal artery were found in all specimens. Arterial supply to the olive varied by location: its anterior aspect was primarily supplied by the anterior spinal artery; the upper portion of the posterior aspect of the olive was supplied by the vertebral artery, the anterior inferior cerebellar artery, and the basilar artery; and the middle and lower portions of the posterior aspect were fed by the vertebral artery and posterior inferior cerebellar artery. These arteries supplied the medulla through the small branches directed toward the olive.

The authors observed a wide anastomotic net connecting the small arteries in this area. These patterns of microvascular supply of the pyramid and olive may deepen the understanding of clinical and pathological conditions resulting from arterial occlusion. The existence of an anastomotic net may account for the rare incidence of medullary infarction in the olive region.

KEY WORDS • medulla oblongata • olive • vertebral artery • anatomical study

Materials and Methods

The arterial supply and microanatomy of the anterior surface of the medulla oblongata and olive were studied in 11 cadaveric specimens. Brains were removed and immersed in a normal saline solution at routine autopsy performed 4 to 8 hours post mortem. The larger vertebral artery was cannulated with a No. 18 polyethylene catheter. The opposite vertebral and both posterior communicating arteries were ligated proximally. The basilar artery and its branches were then flushed with colored silicone latex particles. The ventral surface of each specimen was placed uppermost to allow the cerebellum and brain stem to be seen. Dissections were performed under a surgical microscope and all stages of the dissection were recorded with an attached videocamera.

We examined the perforating branches of main arteries supplying the medulla oblongata between the anterior inferior cerebellar artery (AICA) and C-1 nerve roots. The portion of the medulla oblongata between the pontomedullary sulcus and C-1 nerve roots was divided into four segments: 1) right pyramid; 2) right olive; 3) left pyramid; and 4) left olive. The gross dimensions of the anatomical structures and the length and outer diameter of the main arteries, their branches, and perforating arteries were measured. Arterial branches...
were counted and the relationships between them noted. Detailed drawings were made and photographs were taken at various magnifications.

**Results**

**Anatomical Measurements**

The medulla oblongata had a funnel shape (Fig. 1). Its average width at the C-1 level was 12.2 mm (range 10 to 15 mm) and at its widest portion below the pontomedullary junction was 20.0 mm (range 17 to 24 mm). The distance from the C-1 level to the pontomedullary junction was a mean of 19.9 mm (range 16 to 22 mm).

The right and left pyramids were divided by the anterior median fissure on the ventral surface of the medulla oblongata. The foramen cecum was a triangular-shaped expansion of the anterior median fissure at its termination at the inferior border of the pons. The sixth cranial nerve emerged along the anterolateral sulcus, which extended between the pyramid and the olive. The oval-shaped olive lay between the pyramid and the inferior cerebellar peduncle and had an average length of 11.7 mm (range 9 to 15 mm) on the right side and 10.8 mm (range 10 to 15 mm) on the left. The mean width of its superior portion was 7.1 mm (range 6 to 8 mm) on the right side and 7.5 mm (range 6 to 9 mm) on the left. The average width of the inferior portion of the olive was 4.3 mm (range 3 to 6 mm) on the right side and 4.6 mm (range 4 to 6 mm) on the left (Table 1). Roots of the glossopharyngeal and vagus nerves and those of the cranial division of the accessory nerve were attached to the medulla along a line between the olive and the tuberculum cinereum.

**Arterial Supply to the Medulla**

**Major Arteries.** The vertebral artery in its fourth (intracranial) portion was measured on both sides. The average outer diameter was 3.5 mm (range 3 to 4 mm) on the right side and 3.2 mm (range 2 to 4.5 mm) on the left (Table 2). In two specimens the vertebral artery was larger on the left side, in five it was larger on the right, and in four it was equal size on both sides. The vertebral artery was longer on the left side in five specimens, longer on the right in five, and in the remaining specimen was of equal length on both sides. The mean length of the vertebral artery was 21.5 mm (range 19 to 24 mm) on the right side and 21.7 (range 18 to 26 mm) on the left.

In four specimens the vertebral arteries joined at the level of the pontomedullary junction to form the basilar artery. In six specimens the basilar artery was formed 1 to 7 mm above the junction, and in one specimen, the basilar artery was formed 2 mm below it. The basilar artery was 4.5 mm in mean diameter (range 3.5 to 6 mm).

The AICA originated from the basilar artery in all specimens; its point of origin was a mean of 8.1 mm (range 6 to 11 mm) above the vertebrobasilar junction on the right side and 9.2 mm (range 4 to 13 mm) on the left. The mean diameter of the AICA was 1.3 mm (range 0.8 to 2 mm) on the right side and 1.1 mm (range 0.5 to 2 mm) on the left.

Two major branches of the vertebral artery, the posterior inferior cerebellar artery (PICA) and the anterior spinal artery, were identified in all specimens, although in three
cases there was no true PICA on the left side. In two of these three specimens a branch of the AICA replaced the PICA, and in the third the PICA originated from the basilar artery 10 mm above the vertebrobasilar junction. Whenever the PICA arose from the vertebral artery, its point of origin was at the level of the lower part of the olive.

The PICA had a mean diameter of 1.3 mm (range 0.8 to 2 mm) on the right side and 1.5 mm (range 0.8 to 3 mm) on the left; it was larger on the left side in four cases and on the right side in four others. The PICA originated an average of 16.4 mm (range 3 to 25 mm) proximal to the vertebrobasilar junction on the right side and 17 mm (range 10 to 23 mm) proximal to it on the left.

In all specimens, the anterior spinal artery originated from the vertebral artery distal to the PICA when the PICA originated from the vertebral artery. On average, the point of origin of the anterior spinal artery was 6.5 mm (range 5 to 11 mm) proximal to the vertebrobasilar junction on the right side and 8.5 mm (range 6 to 17 mm) on the left. The anterior spinal artery was absent on the right side in two specimens and absent on the left in one. The mean outer diameter of the anterior spinal artery was 0.7 mm (range 0.5 to 0.8 mm) on the right side and 0.8 mm (range 0.5 to 1.0 mm) on the left; this artery was larger on the left side in four specimens, larger on the right in three specimens, and equal on both sides in a single specimen.

In five cases, a small communicating artery, which we termed “the anterior spinal communicating artery,” connected both anterior spinal arteries at the anterior surface of the medulla oblongata (Fig. 2). Its mean outer diameter was 0.5 mm (range 0.3 to 0.7 mm), and its mean length was 0.9 mm (range 0.8 to 1.0 mm). It was located on average 3.3 mm (range 2 to 5 mm) distal to the origin of the anterior spinal artery.

Small perforating arteries that originated from the vertebral artery were found in all specimens. An average of two perforating vessels were seen on the left side (range one to four) and 2.2 (range one to three) on the right. They were directed toward the olive, the inferior cerebellar peduncle, and along the medullary surface to the cerebellum. These branches widely anastomosed with perforators from the PICA, the basilar artery, and the AICA.

**Perforating Arteries.** A total of 242 perforating arteries was found in our 11 specimens with an average of 22 each (range 19 to 25 perforators) (Table 3). Right medullae oblongatae had 126 perforating arteries (mean 11.5, range nine to 14) and left medullae had 116 (mean 10.5, range nine to 13). All perforators arose from the posterior or posterolateral surfaces of the vertebrobasilar axis, and none from the anterior surface. These branches had an average diameter of 0.3 mm (range 0.1 to 0.8 mm) and an average length of 9.15 mm (range 3 to 24 mm). Twenty-six (10.7%) perforating branches originated from the right vertebral artery and 20 (8.3%) from the left. The basilar artery was the point of origin for 24 (9.9%) perforators; 13 branches on the right side and 11 branches on the left side.

Of 25 (10.3%) perforators originating from the PICA, 15 were located on the right side and 10 on the left. The AICA had 13 (5.4%) branches, four on the right side and nine on the left. Of 134 (55.4%) perforators originating in the anterior spinal artery, 68 branches were on the right side and 66 on the left (Table 3).

**Arterial Supply to the Pyramid**

The main arterial supply for the pyramid came from small branches of the anterior spinal artery. For this study these branches were divided into two major groups: 1) longer tortuous branches that we termed “long circumferential arteries;” and 2) shorter straight branches referred to as “short circumferential arteries.” Points of origin for these branches averaged 4.5 mm (range 2 to 9 mm) below
the origin of the anterior spinal artery on the right side and 4.7 mm (range 1 to 9 mm) on the left.

Eighty-seven long circumferential arteries with an average diameter of 0.4 mm (range 0.2 to 0.5 mm) and an average length of 9.4 mm (range 8 to 13 mm) were found in the 11 specimens. There were 43 long circumferential arteries on the right side, with an average of 3.9 per brain (range two to five), and 44 on the left side, with an average of 4.2 per brain (range two to five). Seventy-seven (88.5%) of these arteries originated from the anterior spinal artery and 10 (11.5%) from the anterior spinal communicating artery (six on the right side and four on the left). A long communicating artery originated from the vertebral artery itself in only one case.

A total of 48 short circumferential arteries were found in all specimens, with an average of 4.36 (range four to six) in each. There were 2.4 (one to four) arteries on the right side and 2.1 (two to three) on the left. Their average diameter was 0.25 (range 0.2 to 0.4 mm) and average length was 5.33 mm (range 3 to 7 mm). All short circumferential arteries arose from the anterior spinal artery. We observed many minute arteries less than 0.1 mm in diameter perforating the pyramids directly from the anterior spinal artery.

Five arterial branches, two from the basilar artery and three from the vertebral artery, contributed to the arterial supply of the pyramid. These branches extended from the surface of the olive. The medial portion of the ventral medullary pyramid was primarily supplied by short circumferential arteries, while the lateral portion was primarily supplied by long circumferential arteries (Fig. 3 left).

**Arterial Supply to the Olive**

A total of 149 vessels perforating the olive were found in all specimens, with an average of 13.5 per brain. Their
The median diameter was 0.3 mm (range 0.28 to 0.40 mm) and median length was 12.1 mm (range 9.12 to 16.27 mm). The major arterial supply for the olive came from branches of the vertebral artery, PICA, anterior spinal artery, basilar artery, and AICA (Fig. 3 right).

**Branches From the Vertebral Arteries.** Branches arising from the vertebral artery followed two main patterns (Figs. 4 and 5). In Pattern A, a single trunk arose from the posterolateral surface of the vertebral artery and divided into three or more small branches at the middle portion of the olive. One or two of these branches perforated the surface of the olive, supplying its inferior middle, upper, and lower portions.

In Pattern B, one or more thin branches arising from the posterior or posterolateral surface of the vertebral artery perforated the surface of the olive separately. Four of the brains had Pattern A on both sides, three had Pattern A on one side and Pattern B on the other, and four brains had Pattern B on both sides.

Forty-two branches from the vertebral artery to the olive were found (mean 3.8 branches per brain, range two to five). There were 23 branches in 11 specimens with an average 2.1 per brain (range one to three) on the right side, and 19 branches with an average of 1.7 per brain (range one to three) on the left. These arteries had an average diameter of 0.38 mm (range 0.2 to 0.8 mm) on the right side and 0.43 mm (range 0.2 to 0.8 mm) on the left. Their median length was 13.2 mm (range 6 to 21 mm) on the right and 13 mm (range 6 to 19 mm) on the left.

Most of these olivary perforators divided into two or more small branches at the inferior border of the olive. Some of these branches ran to the inferior cerebellar peduncle and medullary surface of the cerebellar hemisphere. The point of origin of the vertebral olivary branches was located 7.8 mm (range 0 to 20 mm) on the right side and 7.0 mm (range 1 to 22 mm) on the left side below the vertebrobasilar junction.

**Branches From the Basilar Artery.** We found 22 branches from the basilar artery to the olive in the 11 specimens, with an average of two branches per brain. On the right side, all but three branches originated 3.0 mm (range 1 to 6 mm) above the vertebrobasilar junction, with the...
remaining three arising at the level of the junction; on the left all but three arose 4.2 mm (range 2 to 11 mm) above the junction, with three branches originating at the point of the junction. These basilar artery branches lay on the surface of the pons and pontomedullary fissure to the inferior cerebellar peduncle and then turned upward, where ascendant perforating olivary branches arose in most of the specimens. The average diameter of these branches was 0.4 mm (range 0.2 to 0.8 mm) and their average length was 16.3 mm (range 10 to 24 mm). These basilar artery branches primarily supplied the inferior upper part of the olive.

**Branches From the PICA.** A total of 25 branches from the PICA coursing to the olive were found (average 2.27 per brain, range one to five). Their point of origin was 6.6 mm (range 2 to 10 mm) distal to the origin of the PICA on the right side and 7.5 mm (range 6 to 11 mm) on the left. These branches of the PICA, with an average diameter of 0.3 mm (range 0.2 to 0.8 mm) and an average length of 9.8 mm (range 5 to 19 mm), supplied the inferior lower portion of the olive.

The PICA supplied small branches to the lateral aspect of the medulla and inferior cerebellar peduncle. On the right side a total of 15 branches were found, with an average of 1.36 per brain, and on the left side there were 10 branches with an average of .91 per brain. We could not find any branches in the anterior medulla. All branches of the PICA supplying the lateral medulla were found in the lateral medullary portion.

**Branches From the AICA.** Some of the branches from the AICA supplied the inferior upper part of the olive. We found a total of 13 branches (four on the right side and nine on the left side) with an average of 1.18 per brain (range one to two). The average diameter was 0.3 mm (range 0.1 to 0.4 mm) and average length was 13.2 mm (range 2 to 21 mm). The point of origin of these branches was 8.7 mm (range 5 to 13 mm) distal to the origin of the AICA on the right side and 10.5 mm (range 3 to 18 mm) on the left side.

**Branches From the Anterior Spinal Artery.** Forty-seven of the long circumferential arteries from the anterior spinal artery extended to the superior part of the olive. On the right side there were 24 long circumferential arteries with an average diameter of 0.3 mm (range 0.2 to 0.4 mm) and an average length of 9.1 mm (range 8 to 14 mm). On the left side, 23 long circumferential arteries were seen with an average diameter of 0.3 mm (range 0.2 to 0.4 mm) and an average length of 9.2 mm (range 8 to 11 mm). In one specimen no long circumferential arteries were found on the right side supplying the olive; however, the remaining specimens had an average of 2.4 (range one to four) per brain on the right side, and 2.3 (range one to three) on the left.

The ventral part of the olive was supplied by branches of the anterior spinal artery with an average of 2.3 (range one to four) long circumferential arteries per olive. The rostral third of the dorsal part of the olive was supplied by branches of the vertebral artery, AICA, and basilar artery; the middle third was supplied by branches from the vertebral artery and, in one case, the PICA; the caudal third was supplied by branches from the vertebral artery and PICA (Fig. 3 right).

**Anastomoses.**

A wide anastomotic net was found interconnecting some of the small arteries. On the right side there were nine anastomoses between small arteries in seven specimens: four of these were found between the vertebral artery and the basilar artery, two between the vertebral artery and the PICA, one between the vertebral artery and the AICA, one between the PICA and the anterior spinal artery, and one between branches of the vertebral artery. On the left side there were 14 anastomoses in 10 specimens: three of these anastomoses connected small arteries between the vertebral artery and the AICA, three between the vertebral and the basilar arteries, two between the vertebral artery and the PICA, and three between branches of the vertebral artery.

**Discussion.**

The microvascular anatomy of the major infratentorial vessels has been examined by many authors,17,19,25,27,29,30,33–35,37–39,41,43–45,47 however, most investigated only the major vessels and the internal anatomy of neural structures. We chose to examine the microvascular anatomy of the anterior surface of the medulla oblongata because of its surgical importance and its high density of crucial neural structures.

Branches of the vertebrobasilar system have previously been classified according to arterial length, distribution, and type.17,35,37,43,44,47 We divided our discussion of the arterial supply of the anterior surface of the medulla oblongata into two parts: 1) the anterior surface containing the pyramid; and 2) the lateral surface containing the olive.

**Vascularization of the Pyramid.**

The anterior surface of the medulla (with the pyramid) was generally supplied by branches of the anterior spinal artery on each side (Fig. 3 left). Two types of perforator arose from this artery: shorter straight branches and longer tortuous branches (Fig. 2). The shorter branches supplied the medial part of the pyramid and did not reach the anterolateral sulcus; all arose from the anterior spinal artery. The longer branches usually reached the anterolateral sulcus and perforated the anterior surface of the olive and upper medullary segment. Some of these reached the foramen cecum. The majority of longer branches originated in the anterior spinal artery (88.5%), the remaining 10 (11.5%) arose from the anterior spinal communicating artery and supplied the lateral portion of the pyramid. These findings are similar to observations by other investigators.17,32,37,47 We believe that the anterior spinal communicating artery plays an important role in the vascularization of the upper pyramid.

The anterior spinal arteries from both sides join to form a single artery at the level of C-2 or C-3 in 63% of the population.43,47 Above this level, the pyramid is supplied only by rami of the anterior spinal artery on each side. We could not find any anastomoses on the surface of the pyramid between these small branches other than the anterior spinal communicating artery, which contradicts the findings of others.17,33
Vascularization of the Olive

The lateral surface of the medulla oblongata is more densely vascularized than the anterior surface (Figs. 4 and 5). A total of 149 perforators of the olive and the lateral aspect of the medulla were discovered. Forty-two of these arose from the vertebral artery, 22 branches from the basilar artery, 25 from the PICA, 13 from the AICA, and 47 perforators arose from the anterior spinal artery. The olive was divided into four parts according to its arterial supply: 1) the ventral part was supplied by branches of the anterior spinal artery; 2) the caudal third of the dorsal part was supplied by branches of the vertebral artery, AICA, and basilar artery; 3) the middle third of the dorsal part was supplied by branches from the vertebral artery; and 4) the rostral third of the dorsal part of the olive was supplied by branches from the vertebral artery and PICA (Fig. 3 right). These findings suggest that the predominant arterial supply comes from the vertebral artery. Our results regarding perforators to the olive and paraolivary region differ with the findings in some other studies.17,29,34,37

Anastomoses

A rich arterial supply together with the anastomotic net of the olive found in our study may explain the localization of lateral medullary infarctions that typically occur as a result of obstruction of the PICA or vertebral artery. Postmortem studies reveal that the limits of these infarctions are found at the posterior border of the olive. Medial medullary infarctions are located only on the anterior surface of the medulla oblongata and do not include the olive.1,2,6,8,29,34,37

Clinical Considerations

We found that the lateral medullary area, particularly the olive, had a distinctive pattern of vascularization that may play an important role in brainstem function. The vertebrobasilar system generally has a low blood flow; however, from a hemodynamic point of view, diseases of vertebral origin are much more benign than diseases of internal carotid artery origin. The following important anatomical and physiological facts explain why this is so:10,20,43 the vertebral arteries are paired vessels that unite to form a single basilar artery. Because of this unique feature, there is more potential in the vertebrobasilar system for the development of adequate collateral circulation. Patients with basilar occlusion usually have collateral circulation through the PICA, AICA, and the superior cerebellar artery with late filling of the distal segment of the basilar artery. Patients with vertebral artery occlusion usu-

Fig. 6. Schematic illustration showing the vascular distribution at different levels of the medulla oblongata. AICA = anterior inferior cerebellar artery; ASA = anterior spinal artery; BA = basilar artery; br. = branches; Lbr. = long branches; PICA = posterior inferior cerebellar artery; Sbr. = short branches; VA = vertebral artery.
ally have patent collateral circulation between the contralateral vertebral and basilar arteries.\textsuperscript{3,7,17,37,47}

Some investigators have reported that during the period in which collateral circulation develops (1 to 21 days) any hemodynamic change or alteration of position may be critically important.\textsuperscript{8,12} Although our observation of a rich anastomotic net on the surface of the olives between the branches of the vertebral artery, PICA, AICA, and basilar artery support these assertions, we could not find any major anastomotic connection between the two vertebral arteries.

Observations regarding the lateral medullary, medial medullary, or combined syndromes suggest that ischemic areas rarely include the olivary nucleus.\textsuperscript{1,2,6,8,18,21,32} Our findings support this (Fig. 6). Small-vessel thrombosis in the basis of the pons or pyramid may cause pure motor hemiplegia.\textsuperscript{9,10,22} Lacunae in the cerebellar peduncles and the basis of the pons or pyramid may cause pure motor findings support this (Fig. 6). Small-vessel thrombosis in the pontine and pyramid; and for this reason the surgeon must prepare any anastomotic connections between branches of the anterior spinal artery and other perforators in the pyramidal area.

Surgical Considerations

In the last 30 years many revascularization procedures have been performed for the prevention of brain-stem ischemia in patients with vertebrobasilar insufficiency syndrome.\textsuperscript{3,5,9,13,14,28,36,42} Most of these procedures focused on the surgical treatment of lesions restricted to the intracranial portion of the vertebral artery. This portion comprises the major arterial supply to the lateral medulla and pyramid; and for this reason the surgeon must preserve the small perforating branches in this area. This is difficult, however, since most of these branches arise from the posterior or posterolateral surface of the vertebral artery. Our findings suggest that proximal vertebral artery segments below the PICA and tonsillomedullary segments of the PICA are the most appropriate segments for microsurgical revascularization procedures because they have fewer perforators than other segments of these vessels.

Since all perforating vessels in this study originated from the posterior or posterolateral surface of the vertebrobasilar arterial axis, it follows that the lateral suboccipital and subtemporal surgical approaches would be most appropriate to obtain a sufficient view.

Our findings, together with the results of other authors, may help to explain some clinical features in patients with certain vascular syndromes of the medulla oblongata.

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References

Anatomy of the medulla oblongata and olive


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<table>
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<tr>
<th>Dimension (mm)</th>
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<th>Pyramid</th>
<th>Medulla Oblongata</th>
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TABLE 1
Gross dimensions of the olive, pyramid, and medulla oblongata
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<th>Artery</th>
<th>Diameter (mm)</th>
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<td>Range</td>
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<tr>
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<tr>
<td>BA</td>
<td>4.5</td>
<td>3.5-6</td>
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<td>rt AICA</td>
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<td>lt AICA</td>
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* AICA = anterior inferior cerebellar artery; ASA = anterior spinal artery; BA = basilar artery; PICA = posterior inferior cerebellar artery; VA = vertebral artery; VBJ = vertebrobasilar junction.
<table>
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<tr>
<th>Factor</th>
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<th>Length (mm)</th>
<th>Lt No.</th>
<th>Diameter (mm)</th>
<th>Length (mm)</th>
<th>Total No.</th>
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<td>242</td>
<td>0.34 (0.1–0.8)</td>
<td>9.15 (3–24)</td>
</tr>
<tr>
<td>total to pyramid</td>
<td>73</td>
<td>0.31 (0.2–0.5)</td>
<td>10.30 (5–14)</td>
<td>67</td>
<td>0.32 (0.2–0.5)</td>
<td>8.61 (4–19)</td>
<td>140</td>
<td>0.32 (0.2–0.5)</td>
<td>9.93 (4–19)</td>
</tr>
<tr>
<td>total to olive</td>
<td>77</td>
<td>0.33 (0.2–0.8)</td>
<td>12.0 (5–24)</td>
<td>72</td>
<td>0.34 (0.1–0.8)</td>
<td>12.47 (6–24)</td>
<td>149</td>
<td>0.33 (0.1–0.8)</td>
<td>12.28 (5–24)</td>
</tr>
</tbody>
</table>

*AICA = anterior inferior cerebellar artery; ASA = anterior spinal artery; BA = basilar artery; PICA = posterior inferior cerebellar artery; VA = vertebral artery.